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(54) **SELF-CORRECTING CURRENT TRANSFORMER SYSTEM**

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H01F 27/40	(2006.01)
G01R 35/02	(2006.01)
H01F 38/28	(2006.01)

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CPC *H01F 27/42* (2013.01); *G01R 15/183* (2013.01); *G01R 35/02* (2013.01); *H01F 27/24* (2013.01); *H01F 27/2823* (2013.01); *H01F 27/402* (2013.01); *H01F 38/28* (2013.01); *H01F 2027/406* (2013.01)

(58) **Field of Classification Search**
CPC .. G01R 31/3277; G01R 15/18; G01R 17/02; G01R 19/0092; G01R 31/315; G01R 31/3627; G01R 33/07
See application file for complete search history.

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(57) **ABSTRACT**

A self-correcting current transformer **100** combines a current transformer **113** and self-calibration electronics **115** into one device. The current transformer has a sensor coil **106** with a number of turns that is less than a target number of turns, to cause a secondary current **205** induced in the sensor coil to be greater than a target secondary current **404** corresponding to the target number of turns. A measurement circuit **116** integrated with the transformer, determines an error signal **214** representing how much greater the secondary current is than the target secondary current and outputs the error signal. A current sink circuit **129** integrated with the transformer, shunts an amount of current **216** from the sensor coil, based on the error signal, to reduce a magnitude of the secondary current to match the target secondary current. The measurement circuit and the current sink circuit may be powered by the secondary current.

6 Claims, 5 Drawing Sheets

SELF-CORRECTING CURRENT TRANSFORMER 100
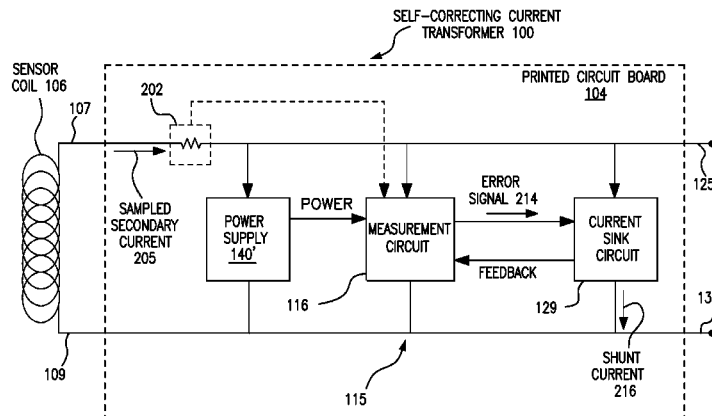
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FIG. 1B

FIG. 1A

FIG. 1C

FIG. 2

FIG. 3

FIG. 4A

SECONDARY CURRENT

SAMPLED SECONDARY CURRENT 205

EXCESS SAMPLED SECONDARY CURENT 406 (REDUCED BY CURRENT SINK CIRCUIT)

TARGET SECONDARY CURRENT 404

410

412

PRIMARY CURRENT

FIG. 4B

ERROR SIGNAL 214

CALIBRATION DATA 310

SAMPLED SECONDARY CURRENT 205

410'

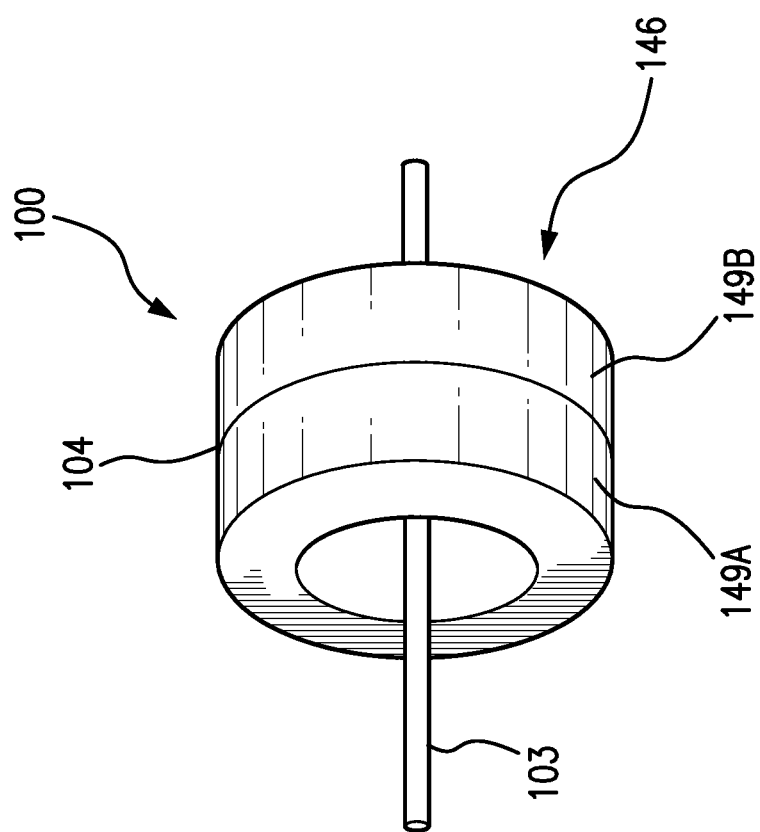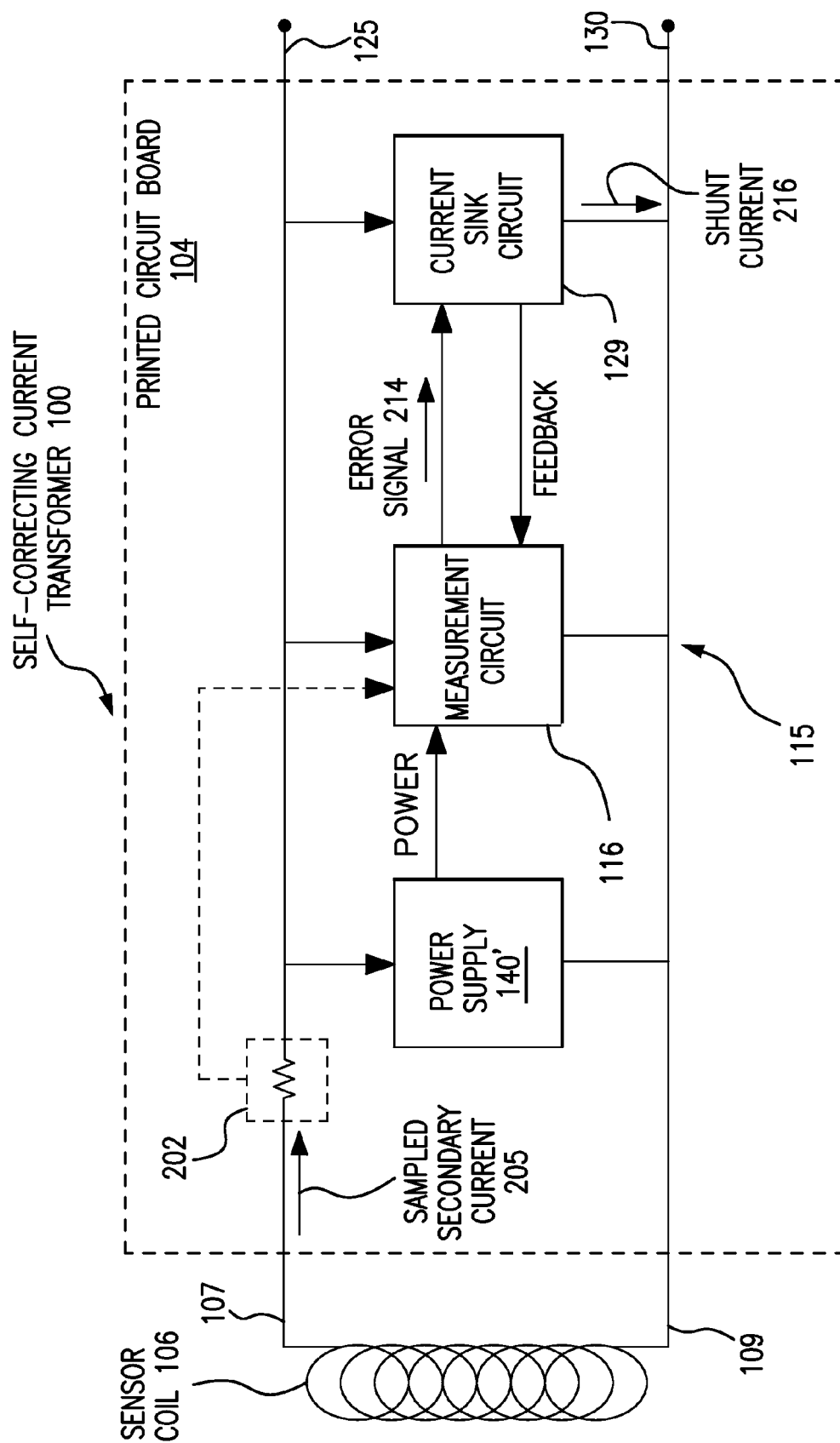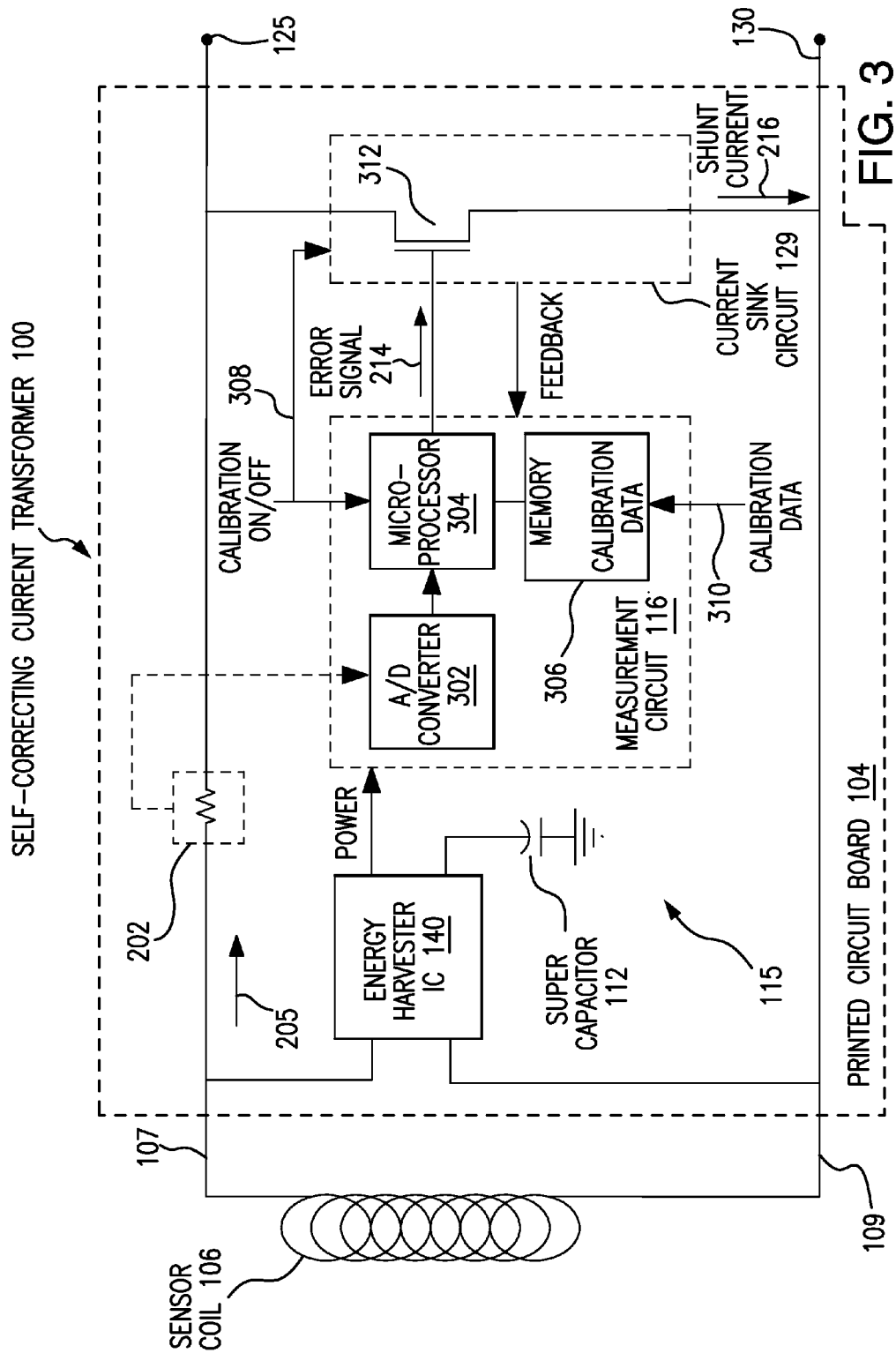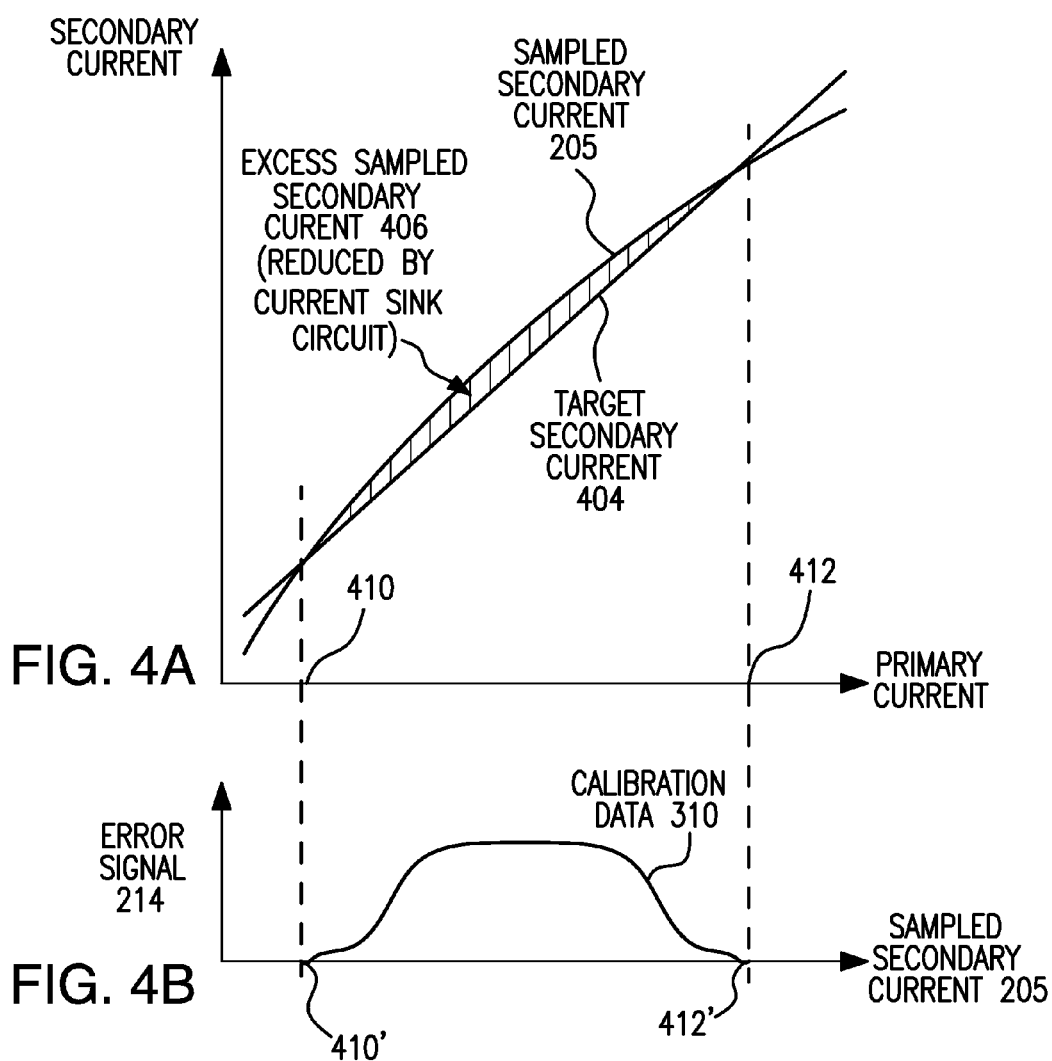412'
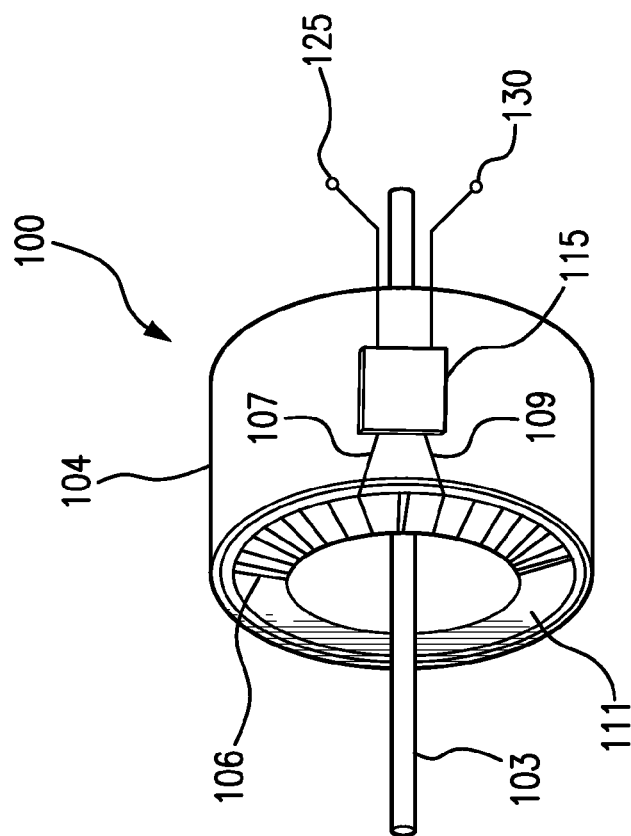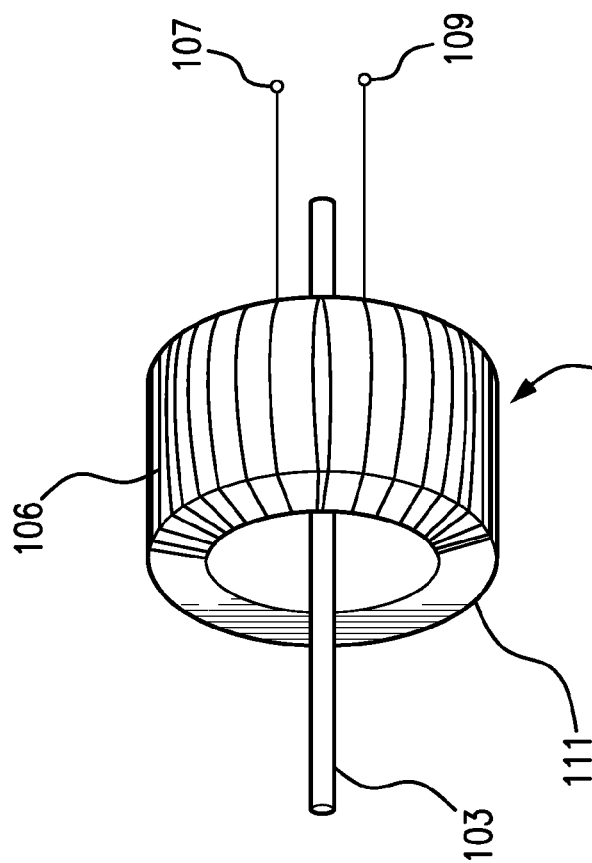
SELF-CORRECTING CURRENT TRANSFORMER SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention disclosed relates to current transformers.

2. Discussion of the Related Art

Current transformers (CTs) are commonly used for monitoring the current in a primary current carrying wire, by measuring with an ammeter or similar device, the induced secondary current in the transformer's sensor coil. An ideal current transformer would deliver to its sensor coil a perfectly accurate ratio of current applied to the primary current carrying wire, enabling the use of a simple ammeter or similar device for measurement. Unfortunately, magnetic losses in the core material of the transformer lead to varying degrees of accuracy. An accurate current transformer with low loss core materials is quite expensive, because of the extensive sampling and testing of the core material that contributes to the accuracy. If a designer were to choose a relatively lower accuracy current transformer for an application, any advantage accruing from a lower cost device will be outweighed by the cost of additional circuitry that must be used in the designer's application, to correct for the lower accuracy. The designer's application will need to include calibration to compensate for a low accuracy transformer's performance characteristics.

SUMMARY OF THE INVENTION

These problems are addressed and solved by the subject invention. The subject Self-Correcting Current Transformer System invention provides a simplified method for the selection of a current transformer for a particular application, by combining a current transformer and self-calibration electronics into a single device. The invention uses a current transformer with a sensor coil having a number of turns that is less than a target number of turns, to cause a secondary current induced in the sensor coil to be greater than a target secondary current corresponding to the target number of turns. A measurement circuit integrated with the current transformer, samples the secondary current as a measure of a primary current. The measurement circuit includes calibration data to determine an error signal representing how much greater the sampled secondary current is than the target secondary current, and outputs the error signal. The calibration data is prepared at the time of manufacture of the transformer. A current sink circuit integrated with the current transformer, receives the error signal and shunts a corresponding amount of current from the sensor coil to reduce a magnitude of the secondary current to match the target secondary current. The measurement circuit and the current sink circuit may be powered by the secondary current from the sensor coil.

In this manner, no additional circuitry or calibration is required in the designer's application, to compensate for a current transformer's performance characteristics.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1A illustrates an example building block of the invention, showing a sensor coil of wire, operating as a secondary coil, wound as a toroidal coil about a toroidal core, having a primary current carrying wire threaded through the toroidal core's center, forming a current transformer.

FIG. 1B illustrates an example embodiment of the self-correcting current transformer invention, wherein the current transformer of FIG. 1A, has an integrated measurement circuit electrically connected to leads from the sensor coil.

FIG. 1C illustrates the example embodiment of the invention, showing the self-correcting current transformer of in FIG. 1B, enclosed in a two piece housing.

FIG. 2 illustrates an example embodiment of the self-correcting current transformer invention, showing the measurement circuit and current sink circuit.

FIG. 3 illustrates an example embodiment of the self-correcting current transformer invention, showing additional details of the measurement circuit and current sink circuit of FIG. 2, wherein the measurement circuit and the current sink circuit are powered by secondary current from the sensor coil.

FIG. 4A illustrates an example graph of secondary current vs primary current for the self-correcting current transformer of FIG. 3.

FIG. 4B illustrates an example graph of an error signal output from the measurement circuit vs the secondary current for the self-correcting current transformer.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Design applications requiring current measurement using a current transformer, typically have a design requirement of a particular magnitude or range of primary current to measure and a design requirement of a particular range or magnitude of output secondary current that is compatible with downstream electronics. A required magnitude of secondary current is refereed to herein as a "target secondary current". For a primary current of the required magnitude flowing through the current transformer, a sensor coil having a number of turns sufficient to output the target secondary current, is referred to herein as a sensor coil with a "target number of turns".

In an example embodiment of the invention, the current transformer has a sensor coil with a number of turns that is less than a target number of turns, to cause a secondary current induced in the sensor coil by the required primary current, to be greater than the target secondary current corresponding to the target number of turns. A measurement circuit integrated with the current transformer, samples the secondary current as a measure of the primary current. The measurement circuit includes calibration data to determine an error signal representing how much greater the sampled secondary current is than the target secondary current and outputs the error signal. The error signal is determined based on calibration data prepared at the time of manufacture of the transformer, to adjust the secondary current. A current sink circuit integrated with the current transformer, receives the error signal and shunts a corresponding amount of current from the sensor coil to reduce a magnitude of the secondary current to match the target secondary current.

FIG. 1A illustrates an example building block of the invention, showing a sensor coil or secondary coil 106 of wire, wound as a toroidal coil about a toroidal core 111, having a primary current carrying wire 103 threaded through the toroidal core's center, forming a current transformer 113. The current transformer 113 couples the primary 103 and secondary 106 coils, so that the secondary current is approximately proportional to the primary current. The current transformer's primary circuit consists of a single turn of conductor 103, with a secondary 106 of many tens or hundreds of turns. The current transformer's sensor coil 106

has a number of turns that is less than a target number of turns, to cause the secondary current induced in the sensor coil **106** to be greater than a target secondary current corresponding to the target number of turns. In alternate embodiments, the core may be a laminated core or an E-core. In alternate embodiments, the primary circuit may have multiple primary turns, or multiple passes of the primary may be made through an open window style current transformer.

FIG. 1B illustrates an example embodiment of the self-correcting current transformer **100**, wherein the current transformer **113** of FIG. 1A, has a flexible printed circuit board **104** wrapped about the outside circumference of its toroidal coil **106**. Measurement and signal conditioning circuits **115** on the printed circuit board **104**, are electrically connected to leads **107** and **109** from the sensor coil **106**, to sample secondary current induced in the sensor coil **106** as a measure of primary current in the primary current carrying wire **103**. FIG. 1C illustrates the example embodiment of the invention, showing the self-correcting current transformer of in FIG. 1B, enclosed in a two piece housing **146** comprising mating covers **149A** and **149B**, which may be composed, for example, of an organic polymer plastic or a ceramic material having electrically insulating properties.

FIG. 2 illustrates the example embodiment of the invention, showing the measurement and signal conditioning circuits **115** of the self-correcting current transformer **100**. The measurement circuit **116** samples the secondary current **205** induced in the sensor coil **106**, which passes through the burden resistor **202**. The measurement circuit **116** determines an error signal, shown in FIG. 4B, representing how much greater the sampled secondary current **205** is than the target secondary current **404** shown in FIG. 4A. A current sink circuit **129** is electrically connected to the leads **107** and **109** from the sensor coil **106**, receives the error signal from the measuring circuit **116**. The current sink **129** shunts an amount of current **216** from the leads of the sensor coil to reduce a magnitude of the secondary current **205**, so as to match the target secondary current **404**.

The example measurement circuit **116** may include calibration data **310** shown in FIG. 4B, to determine the error signal **214** representing how much greater the sampled secondary current **205** is than the target secondary current **404**, and outputs the error signal **214**. The calibration data **310** in the measurement circuit **116** is prepared at the time of manufacture of the current transformer **113**, to adjust the secondary current. The current sink circuit **129** receives the error signal **214** and shunts a corresponding amount of current **216** from the sensor coil **106** to reduce a magnitude of the secondary current output at the terminals **125, 130**, to match the target secondary current **404**.

FIG. 3 illustrates an example embodiment of the self-correcting current transformer invention, showing additional details of the measurement circuit **116** and current sink circuit **129** of FIG. 2. The measurement circuit **116** and the current sink circuit **129** are powered by the secondary current from the sensor coil. The example measurement circuit **116** and the current sink circuit **129** may be powered by an energy harvester integrated circuit (IC) **140** and super capacitor **112** that draw power from the secondary current **205** from the sensor coil **106**.

The example measurement circuit **116** may comprise an analog-to-digital converter **302** that samples the secondary current **205** passing through the burden resistor **202**. The digital value of the sampled secondary current **205** is output to the microprocessor **304**. A memory **306** stores calibration data **310** prepared at the time of manufacture of the trans-

former, to adjust the secondary current **205**. The microprocessor **304** determines the error signal **214** representing how much greater the sampled secondary current **205** is than the target secondary current **404** and outputs the error signal **214** based on calibration data **310**.

The example current sink circuit **129** may comprise a field effect transistor **312** operating in a resistive region of operation, with its gate connected to the microprocessor **304**, to receive the error signal **214**. The field effect transistor (FET) **312** conducts a shunt current **216** from the lead **125** of the sensor coil in response to the error signal **214**, to reduce a magnitude of the secondary current **205** so as to match the target secondary current **404**. In an alternate embodiment, the example current sink circuit **129** may comprise a transistor switched by pulse width modulation from saturation to off, at a high frequency.

During the manufacture of the example self-correcting current transformer **100**, an example calibration process may be performed to compensate for variations in accuracy of transformer's performance characteristics. The calibration on/off input **308** is turned on, setting the microprocessor **304** into calibration mode. The calibration on/off input **308** disables the current sink circuit **129**. A primary current is passed through the primary current wire **103**, having a sequence on known primary current values, for example from 450 to 550 Amperes. A precision current measuring device is connected to the output terminals **125** and **130** and a corresponding sequence of secondary current **205** values from the sensor coil, is measured, for example from 4.5 to 5.5 Amperes.

A goal of the example calibration process is to make the self-correcting current transformer **100** output a required target secondary current of, for example, 5 Amperes, for a primary current of 500 Amperes. The sensor coil **106** has a number of turns that is less than a target number of turns, to cause the secondary current **205** induced in the sensor coil **106** to be greater than the target secondary current **404** corresponding to a target number of turns. An error signal representing how much greater the measured secondary current **205** is than the target secondary current **404**, is determined during the calibration process, for the measured sequence of secondary current **205** values. Based upon the conduction characteristics of the current sink circuit **129**, a sequence of values for the error signal **214**, is compiled as the calibration data **310**. The calibration data **310**, may be, for example, the value of the gate potential that is applied to the gate of the FET device **312**, to pass the desired shunt current **216**, to reduce the magnitude of the secondary current **205** to match the target secondary current **404**. The calibration data **310** is then stored in the memory of the measurement circuit **116** at the conclusion of the calibration process.

FIG. 4A illustrates an example graph of secondary current vs primary current in a range **410, 412**, for the self-correcting current transformer **100**, showing the sampled secondary current **205** output from the sensor coil **106**, the target secondary current **404**, and the excess sampled secondary current **406** that is to be reduced by the current sink circuit **129** of FIGS. 2 and 3, to proportionally reduce the sensor output current **205** to produce a corrected output current that matches the target secondary current **404**, with minimal error.

FIG. 4B illustrates an example graph of the error signal **214** output from the measurement circuit vs the sampled secondary current **205** in a range **410', 412'**, the error signal **214** being based on the calibration data **310** in the measure-

ment circuit **116**, the error signal **214** being input to the current sink circuit **129** of FIGS. **2** and **3**.

Although specific example embodiments of the invention have been disclosed, persons of skill in the art will appreciate that changes may be made to the details described for the specific example embodiments, without departing from the spirit and the scope of the invention.

The invention claimed is:

1. A self-correcting current transformer, comprising:

a sensor coil of wire wound about a core, the sensor coil being configured as a secondary coil having a number of turns, the core having a primary current carrying wire as a primary coil, the number of turns of the sensor coil being less than a target number of turns, to cause a secondary current induced in the sensor coil from current in the primary current carrying wire, to be greater than a target secondary current corresponding to the target number of turns;

a measurement circuit electrically connected to leads from the sensor coil, the measurement circuit being configured to sample the secondary current induced in the sensor coil as a measure of primary current in the primary current carrying wire, the measurement circuit being configured to determine an error signal representing how much greater the sampled secondary current is than the target secondary current, and the measurement circuit being configured to output the error signal; and

a current sink circuit electrically connected to the leads from the sensor coil, the current sink circuit being configured to receive the error signal from the measurement circuit and to shunt an amount of current from the leads of the sensor coil to reduce a magnitude of the secondary current to match the target secondary current.

2. The self-correcting current transformer of claim **1**, wherein the error signal is determined based on calibration data included in the measurement circuit, to reduce the magnitude of the secondary current to match the target secondary current.

3. The self-correcting current transformer of claim **1**, wherein the current sink circuit comprises a transistor operating in a resistive region of operation.

4. The self-correcting current transformer of claim **1**, wherein the measurement circuit and the current sink circuit are enclosed with the sensor coil in a housing through which the primary current carrying wire may be threaded.

5. The self-correcting current transformer of claim **1**, wherein the measurement circuit and the current sink circuit are powered by the secondary current from the sensor coil.

6. The self-correcting current transformer of claim **1**, wherein the sensor coil is wound as a toroidal coil about a toroidal core.

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